MAN'S IMPACT ON SEDIMENTARY ENVIRONMENTS AND PROCESSES

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ABSTRACT

During the past 75 years, man has dramatically modified the morphology, sedimentary environments, and sedimentary dynamics of Biscayne Bay, especially that portion north of the Key Biscayne-Coconut Grove area. Man's impact results mainly from five influences: creation of artificial cuts across Miami Beach, obstruction and modification to the natural sediment movement on the ocean beaches, dredge and fill projects for waterways and land fill, construction of drainage canals across marginal freshwater marshes, and causing increased turbidity.

Construction of Baker's Haulover cut (1925) and Government Cut (1905) across Miami Beach have altered the shore sediment budget and caused changes in the salinity and circulation of northern Biscayne Bay. These changes have in turn caused erosion along portions of the ocean beaches and major changes in the sedimentary environments of northern Biscayne Bay.

The construction of inlets through and seawalls, groins, and jetties along the ocean-facing beaches from Miami Beach to Key Biscayne has obstructed both natural sediment drift along the shore and erosion-accretion cycles transverse to the shore trend. Most seriously affected are the beaches south of Government Cut. These have been cut off from natural beach sand replenishment for the past 50 years and are rapidly eroding.

Dredge and fill projects in northern Biscayne Bay have dissected this once shallow, elongate mangrove-rimmed bay into a lagoonal complex in which deep moats and channels border the dredged and seawalled fill islands and Bay margins. Unbulkheaded environments influenced by dredging are a persistent source for the gradual re-introduction of turbidity (particulate suspensions) into the water column. Dredge and fill projects in central and southern Biscayne Bay are scattered and have had only local impact on Bay environments.

Drainage canals criss-crossing bay margin swamps and margins have caused freshwater marl flats and swamps to yield to mangrove swamps or upland scrub environments.

A marked increase in turbidity of the Bay waters has accompanied urbanization of the northern and central Bay sectors. Although this may have been initially caused by dredging operations in the mid-twenties and large volumes of raw sewage discharge in the 1920-1955 period, some other influence is perpetuating high turbidity levels today. Of the possible influences, re-release of dredge spoil and the loss of "turbidity inhibitors" should receive focused study.

Resultant from this impact there have been major changes in the sedimentary environments of and marginal to northern and central Biscayne Bay and minor changes to the south. Especially serious is (1) the conversion of large portions on the northern Bay bottom from a sea-grass stabilized shelly mud to a mobile soft to flocculent ooze bottom, and (2) the destruction of a major percentage of the turbidity and energy adsorbing mangrove swamp shoreline along northern Biscayne Bay.

Future research must focus on (a) fine-grained sediment dynamics and (b) mapping the spatial and temporal gradients of the bio-sedimentary environments. Also urgently needed is an effective mechanism to input present and future knowledge of this unique urbanized Bay system into regulatory guidelines.

INTRODUCTION

Man's influence on the morphology, sedimentary environments, and sedimentary dynamics of Biscayne Bay has nearly entirely occurred during the past 75 years. There are five main ways in which man has modified sedimentation.

1) Creation of artificial cuts across the seaward barrier islands and deepening natural cuts through the seaward margin have altered the shore sediment budget and caused changes in salinity and circulation of northern Biscayne Bay thus modifying bottom sedimentary environments.

2) Ocean-facing beaches of the sand islands bordering northern Biscayne Bay are severely eroding, partly because of natural processes and partly because of sand loss into the Bay through artificial cuts and sand drift blockage of seaward extending jetties.

3) Dredge and fill operations have dissected northern Biscayne Bay into a lagoonal complex, eliminated the mangrove swamp fringe from most of the northern and much of the central Bay sector, created spoil islands and shoals throughout the Bay, and been both a short-term and persistent source for increased turbidity.

4) Drainage canals have connected fresh water marshes and marl flats in the marine environment.

5) Increased turbidity in the north and central Bay sectors accompanied urbanization. This has caused major changes in bottom sedimentary environments, substrate mobility and dynamics of fine particulate sediment and adsorbed pollutants.

Some of man's modifications have had an immediate and direct effect on the morphology, sedimentary environments and sediment dynamics of the Biscayne Bay area. Other changes, as persistent turbidity and beach erosion, are indirect results of man's intervention, and the exact cause is difficult to determine.

In assessing man's influence on the morphology of Biscayne Bay and on the contained sedimentary environments and processes, there are four important questions that must be addressed and resolved. These are:

1) What was it like before man's presence? What was the influence of the environment or process on the system? What were the natural trends of the system?

2) What were the direct effects of a man-induced modification?

3) What were the indirect effects--either to adjacent environments or at a later time? What indirect effects might a modification cause?

4) Of those detrimental changes to the system, is the original, formative cause perpetuating the detrimental change, or is the detrimental change now being perpetuated by some other influence of subsequent urbanization.

Each of these questions must be properly addressed and resolved to achieve a meaningful understanding of man's impact on Biscayne Bay--one that can be used both to design a proper urban development program for southern Biscayne Bay and to create a cost-benefit evaluation for the recovery of northern Biscayne Bay.

ARTIFICIAL CUTS ACROSS SAND ISLAND BARRIERS

Prior to 1900 Miami Beach formed a complete sand barrier between the ocean and Biscayne Bay as far south as Norris Cut at the south end of what is now Fisher Island. Norris Cut was a very shallow washover that had developed very little since its formation in the great hurricane of 1835 (Chardon, this volume). Thus, prior to man's development of Biscayne Bay, Bear Cut, separating Virginia Key and Key Biscayne, was the first major tidal pass through the long sand island barrier.

In 1905 Government Cut was cut across the south portion of Miami Beach (Figure 1). The separated southern tip, with fill added in the 1920's on the bayward side, became Fisher Island. The original cut was small and not supported by jetties. Sand rapidly worked bayward along both sides of the jetties. "Originally 18 feet deep and 60 feet wide, Government Cut was enlarged to a depth of 20 feet and a width of 300 feet in 1912. The depth was increased to 25 feet in 1925 and 30 feet in 1930. The jetties were extended to their present length between 1926 and 1929, 4000 feet for the north jetty and 300 feet for the south jetty." (Hannon, et al, 1972)

The Miami Shipping Channel, extending from Government Cut across Biscayne Bay to the mainland shore, was 18 feet deep by 1915, 25 feet by 1925, and 30 feet in 1930 (McNulty, 1970). Between 1920 and 1925 Carl Fisher constructed deepwater channels on the west and south sides of Fisher Island with the hopes of making the island a great deepwater port. Though never realized, he converted Norris Cut, separating Fisher Island

and Virginia Key, from a shallow tidal washover to a tidal channel 15 to 20 feet in depth across most of the pass.

As the shipping channel was extended westward across Biscayne Bay towards the mainland, Lumis and Dodge islands and McArthur Causeway accumulated as spoil islands. Subsequent construction of tributary shipping channels and island bulkheading led to the completion of Dodge Island in 1961. This opened as Miami's port facility in the late 1960's.

Government Cut and the Miami Shipping Channel are presently being deepened to 42 feet.

Baker's Haulover, the narrow sand neck at the north end of Miami Beach was artificially breached in 1924-1925 to aid fishing boats and tourist charters. Jetties extend seaward from the beach only a short distance.

Three striking changes have resulted from the construction of Government Cut and Baker's Haulover. Natural sand nourishment to adjacent beaches has been disrupted by Government Cut jetties; at Baker's Haulover sand is being swept into Biscayne Bay and lost from the beach system; and the salinity, circulation and sedimentary environments of northern Biscayne Bay have changed as these cuts increased exchange with offshore water.

Government Cut, with granite jetties extending three-quarters of a mile seaward of the shore and a 30 foot channel trough, has provided an essentially complete block to the natural southerly drift of beach sand. Sand has built up along the shore of South Miami Beach producing an exceptionally wide and stable beach from the north jetty north to about 14th Street. To the south, sediment starvation has caused serious beach erosion on Fisher Island and Virginia Key for the past 50 years (Figure 1) and is beginning to adversely effect the beaches of Key Biscayne. This is discussed in the next section.

The small jetties extending seaward from Baker's Haulover cut are not a serious obstacle to the natural southerly drift of sand nourishment in the nearshore zone. Much of the sand passing the inlet, however, is swept into the channel and deposited as a flood tide sand delta within the Bay. This loss of sand from the beach system is sufficiently great to necessitate (a) artificial nourishment of the beaches south of Baker's Haulover, (b) repeated dredging of Baker's Haulover cut and channel, and (c) occasional redredging of the intracoastal waterway smothered by the growing sand tidal delta.

The construction of Government Cut and Baker's Haulover cut and the deepening of Norris Cut has converted Northern Biscayne Bay from a seasonally brackish, seasonally hypersaline shallow environment of sluggish circulation into a bay in which near normal salinities are maintained. This has had a profound effect on the bay bottom and bay margin sedimentary environments (Teas, Wanless and Chardon, this volume).

SHORE EROSION

There are three main types of natural shorelines in the Biscayne Bay Region--rocky limestone, mangrove swamp and sandy beach.

Rocky Shorelines

Rocky shorelines are along the seaward side of the seaward bounding islands from Soldier Key to Key Largo and along the mainland shoreline in the Snapper Creek area. This Pleistocene limestone rock erodes only very slowly through biologic corrosion and is not a problem.

Mangrove Shorelines

Mangrove swamp shorelines occur along the more protected portions of Biscayne Bay. They are naturally eroding or accreting primarily depending on their exposure to storm waves. Berberian (unpublished data), studying sequential charts of southern Biscayne Bay and Card Sound, found that northward facing swamp shorelines had moderately to severely eroded in historical times, whereas southward and westward exposed shorelines had remained stationary or accreted. The mangrove shore fringe provides a very important energy buffer against hurricane storm waves but is commonly severely damaged by them (see Warzeski, this volume). Mangrove shorelines have generally been totally destroyed in areas of bay margin dredge and fill programs. Elsewhere they appear unaffected by urbanization (see, however, Teas, this volume). The U.S. Geological Survey estimated that the coastal mangrove forest of about 15 per cent of Biscayne Bay had been destroyed as of 1973 (U.S.G.S., 1973). Most of this destruction took place in northern Biscayne Bay during dredge and fill operations of the mid 1920's to late 1940's.

Mainland Beaches

Sandy beaches occur at scattered intervals along the mainland shore of Biscayne Bay from Coconut Grove south to Barnes Sound. Beaches of Biscayne Bay and Card Sound are fine quartz sand; those of Barnes Sound are shell hash. Except where artificially nourished or maintained, mainland beaches are only a thin veneer of sand over an eroding mangrove peat platform or swamp margin. These beaches have fared well during urbanization except where small boat or drainage canals have disrupted the natural southerly drift of sand or where dredge and fill operations have directly obliterated them. These beaches are naturally migrating landward and are in part dependent on sand reworked out of the mangrove peat deposits for nourishment.

Ocean Beaches

Since the 1926 hurricane that ended Miami's first growth boom, beach erosion has been a serious and persistent problem along the developed ocean facing beaches of Miami Beach, Fisher Island, Virginia Key, and Key Biscayne. A part of this problem is caused by man's attempting to obstruct the natural trend of the system; part results from man's modification of sand movement.

Miami Beach is a narrow sand island barrier which was, prior to man's involvement, naturally migrating slowly landward or stationary. Superimposed on this gradual trend was a shorter term beach cycle. The beach zone would erode during major storms and the winter season and naturally restore itself during quieter periods between. Construction of seawalls and hotel fronts near high water mark during the early 1920's left the structures and the beach earmarked for trouble during the 1926 hurricane. These structures both blocked the natural erosion-accretion cycle of the beaches and obstructed gradual natural landward migration of the island. Despite the construction of extensive groin systems along Miami Beach, the beach has never returned to its original state because (a) the seawalls, once exposed to surf action, reflect much of the wave energy and sand seaward, (b) the groin systems shift the zone of longshore drift to an offshore bar causing potential sand replenishment to bypass the groined beach zones, and (c) the beach was dependent on sand recycled by gradual landward migration. Today, sand is carried landward of the beach system by wind and storm surge and permanently lost from the system.

Baker's Haulover at the north end of Miami Beach has diverted large amounts of the natural beach sand nourishment into Biscayne Bay causing accentuated erosion along the beach to the south.

Government Cut jetties are an essentially complete block to the natural southerly drift of beach sand and have prevented natural sand nourishment to Fisher Island, Virginia Key, and Key Biscayne for the past 50 years. The Corps of Army Engineers (1966) estimate that about 50,000 cubic yards of sand per year is drifting southward past Baker's Haulover every year. Probably about this same amount is being blocked by Government Cut jetties from nourishing the barrier island system to the south. The direct and indirect sequence of results from this blockage are striking and over the next ten years will become an extremely serious problem.

1. The original natural beach of Fisher Island is essentially completely lost, exposing the rubble land fill behind at the shoreline. The shoreline is eroding 5 to 15 feet per year even though made of rubble limestone and even though shielded by Government Cut jetties from northerly winter storm waves (Hannon, et al., 1972). The subtidal sand reservoir seaward of the island has been completely stripped away exposing the pre-existing limestone surface.

2. All of Virginia Key beaches have severely eroded during the past 70 years. The northern portion has retreated over 300 feet, partly in response to sediment starvation and partly in response to sand loss to the deep dredged portions of Norris Cut. Two major beach nourishment programs in 1969 and 1973 by the Corps of Engineers have attempted to offset this erosion. The latter program implanted 13 granite rubble groins along the beach and infilled with 100,000 cubic yards of sand.

3. A broad seagrass stabilized platform extended nearly one mile seaward of Virginia Key Beach. Nearly 80 per cent of the seagrass bed has been lost during the past 30 years because of inadequate natural sediment renourishment to the offshore platform (Figure 2). Much of the sand floor exposed by seagrass bed loss was very fine and has been swept into suspension and carried from the system. As a result, the shallow seagrass stabilized offshore platform, once protecting the beaches from offshore wave energy, is now rapidly deepening, leaving the beaches exposed to increased storm waves and erosive processes (Wanless, 1975).

4. As sediment is depleted from the northern area, Key Biscayne is beginning to feel the effects of sediment starvation. Serious shore erosion on Key Biscayne presently is limited to the northern shore of Key Biscayne (Crandon Park). This shore was nourished in 1969 and has since been maintained by a careful recycling program for sand blown landward from the beach system. The sand tidal deltas on the seaward and landward ends of Bear Cut have been extensively remobilized into the littoral drift system during the past ten years.

5. Sand for the 1969 renourishment programs on Key Biscayne and Virginia Key public beaches was derived by cutting a sand borrow pit 1,500 offshore of northern Key Biscayne (Figure 3). On most beaches this standard 1,500-foot distance is well beyond the zone of active littoral drift. In this case, the pit cut into the shallow littoral sand platform, partly taking sand destined for beaches to the south and partly cutting in the grass stabilized portions of the platform. Several serious changes have occurred on this littoral platform since 1969. First, the borrow pit has slowly migrated landward (van de Kreeke, personal communication) causing additional erosion of the seagrass beds. Second, sand eroded from the borrow area has, during the past year, spread rapidly across the broad

seagrass bed landward causing massive smothering of the seagrass carpeted bottom. The author is seriously concerned that this smothering will be followed by a sequence of events similar to that documented off Virginia Key's beaches.

Beaches along the developed central sector of central Key Biscayne have evolved much the same problems as the developed beaches of Miami Beach--resulting from bulkhead construction too near high water mark.

A striking zone of beach erosion can be seen at Cape Florida, the south tip of Key Biscayne. The lighthouse, built some distance inland in the early 1800's was nearly lost to the sea during Hurricane Betsy in 1965. Severe erosion at the point probably results from two causes. First, the Cape Florida Channel, bordering Key Biscayne, was extensively deepened and enlarged in 1949-1950 in deriving land fill for the southern third of Key Biscayne. Second, a seawall constructed at that time extends from the lighthouse on around the bayward side of Key Biscayne. These two changes (a) create a deep channel into which sand, carried to the Cape, is easily lost from the beach system and (b) eliminate the narrow beach along the western side of the Cape which may have served as a landward sand reservoir to the Cape.

DREDGE AND FILL PROJECTS

Nearly one half of the surface sedimentary environments within and marginal to northern Biscayne Bay have been directly altered by dredge and fill operations during urbanization. This intensity decreases southward, and south of Key Biscayne and Coconut Grove dredge and fill modifications are few and scattered. South Biscayne Bay, Card Sound, and Barnes Sound are largely in their natural form except for northern Key Largo, the Card Sound road, the inland marsh south of Turkey Point, and along U.S. 1 at the south end of Barnes Sound. Dredgings were for two purposes--to create waterways (with resultant spoil island by-products) and to provide landfill (with resultant borrow pits).

Waterways

The first significant dredging operation in Biscayne Bay was a small channel extending "across the shallows between the mouth of the Miami River and Cape Florida in the late 1890's" (McNulty, 1970).

The intracoastal waterway is maintained as a dredged channel from the north end of Biscayne Bay, south along the western side of Biscayne Bay to Rickenbacker Causeway. To the south, it only maintained by dredging across Featherbed Bank, Cutter Bank at the south end of Biscayne Bay, and Card Bank at the south end of Card Sound. Unbulkheaded spoil islands and shoals parallel the margins of the dredged portions (see base map). Unlike other dredge and fill programs, the intracoastal waterway must periodically be redredged to maintain navigable depth.

In addition to the intracoastal waterway, numerous smaller dredged waterways with adjacent spoil banks extend westward from the intracoastal waterway to the mainland. The oldest is perhaps that extending into the Deering estate just south of Rickenbacker Causeway. Chicken Key (south of Shoal Point) is dredge spoil from the canal and basin extending into Cutler power plant. A barge canal joining the intracoastal waterway and Turkey Point nuclear power plant is the largest and most recent major dredged tributary waterway.

By far the most massive dredging program in the Biscayne Bay area has been the sequential deepenings and expansions of the Miami Shipping Channel. The present three year dredging project is deepening the channel to 42 feet from the offshore margin of the continental shelf to the mainland turning basin. This has stressed available sites for dumping spoil. While earlier dredgings have provided spoil for filling the southern corner of Miami Beach, Fisher Island, McArthur Causeway, Dodge Island and Lumis Island, the current program has dumped spoil on two large offshore sites, on the beach at the south end of Miami Beach, over a large area at the north end of Virginia Key, on the mainland at the head of the channel and on Lumis Island. Suitable dredged sands were also used for the 1973 Virginia Key beach nourishment program.

Other dredged channels across Biscayne Bay provide pathways for pipelines and electrical conduits. A pipeline channel extends from the mainland to Virginia Key and a second pipe corridor crosses Biscayne Bay to central Key Biscayne.

Land Fill

Dredging operations for the purpose of obtaining land fill have most extensively modified northern Biscayne Bay. Major modifications occurred between 1919 and 1927 with the creation of the numerous residential fill islands bordering McArthur Causeway, Venetian Causeway, and 76th Street Causeway, the filling and bulkheading of most of the mainland shore from the Miami River north to 76th Street Causeway, and the bay shore of Miami Beach north to Bal Harbour. Subsequent projects have filled and bulkheaded most margins of northern Biscayne Bay, the mainland shore from the Miami River south past Coconut Grove, and scattered areas to the south.

Six causeways further dissect northern Biscayne Bay. McArthur Causeway (1926), Venetian Causeway (1926), 76th Street Causeway (1940), Rickenbacker Causeway (started in 1942), Broad Causeway, and Julia Tuttle seagrass bed landward causing massive smothering of the seagrass carpeted bottom. The author is seriously concerned that this smothering will be followed by a sequence of events similar to that documented off Virginia Key's beaches.

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Causeway (1959) each contain long strips of roadway fill bordered by deep borrow channels. Additional dredging in conjunction with Rickenbacker Causeway created land for the Miami Marine Stadium on the west side of Virginia Key.

Two land fill operations have significantly modified the morphology of adjacent tidal passes. The rounded south end of Virginia Key was dredged up from sediment of the sandy tidal bars in Bear Cut. The southern third of Key Biscayne, once a low complex of sand ridges, mangrove swamps and brackish ponds, was filled in 1949-1950 with sediment from the adjacent Cape Florida channel and Safety Valve flats. Bulkheading the bayward side eliminated the narrow sandy beach, inhibiting natural fluctuations of sand around the Cape.

The bay side of central Key Biscayne was filled and bulkheaded during the late 1940's and early 1950's, the southern part being molded into a series of finger canals.

This extensive and varied assemblage of dredge and fill operations has caused major direct and indirect changes on the morphology, sedimentary environments, and sedimentary dynamics of the Biscayne Bay region.

1) Each dredge and fill operation has directly destroyed the existing bottom sedimentary environment in the area of dredging and directly smothered an equal or greater area where the spoil or fill was deposited. In addition, fine muds carried in suspension from the dredging operation blanket a much broader area. Some dredge and fill projects have carefully controlled the release of suspended sediment and cause only minor stress on adjacent environments. Other projects have spread tons of silt and clay sized mud across adjacent grassy bay bottoms. For example, the 1973 shore nourishment of Virginia Key released large volumes of mud into Bear Cut. Grass beds as much as one-half mile from the project were covered with up to two inches of mud.

2) The combined result of dredging for island and bay margin landfill, causeways, port facilities, and intracoastal waterways has converted northern Biscayne Bay from a long shallow mangrove-lined bay open to the south into a dissected lagoonal complex of highly variable depth. Fill islands and much of the shoreline are bordered by deep moats, holes, and channels. Wave reflecting seawalls replace the energy adsorbing mangrove margins.

3) The most serious long-term impact of dredge and fill projects appears to be the creation of three artificial environments that persistently re-release fine mud into the bay waters for many years after the project. (a) Unbulkheaded fill islands and shorelines are gradually eroded both by day to day waves and currents and by storm waves. The large amounts of contained mud are persistently reintroduced into the water column. (b) Shallow spoil banks are similarly in disequilibrium with the wave and current climate and, unless stabilized by mangrove or seagrass cover, are a persistent source for particulate suspensions. (c) The fine muds spread widely across adjacent sedimentary environments during dredging are only partly incorporated into that bottom environment. Much is persistently redistributed via the water column during succeeding years.

DRAINAGE CANALS

Small drainage canals dissect much of the lowlying mangrove swamp, marl flats and freshwater marshes bordering Biscayne Bay. These were dredged to drain lowlying areas in preparation for agriculture use or development or for mosquito control.

Sea water penetration of the drainage canal networks has caused mangrove environments to rapidly expand landward across the scrub mangrove and marl flats behind (see Teas, this volume). Those fresh water marsh zones not invaded by salt water have mostly changed to upland scrub.

SEDIMENTARY ENVIRONMENTS

Early newspaper accounts describe northern Biscayne Bay as having crystal clear waters and a lush seagrass carpet on the shallow bay bottom. Core borings confirm that such an environment existed prior to urbanization. The shelly white muds permeated by seagrass rootlets and holes of burrowing organisms are similar to those found beneath the seagrass stabilized shelly mud bottoms of central Biscayne Bay today.

Seagrass cover was largely lost from all but the very shallow portions of northern Biscayne Bay between 1925 and 1956. Today most of the moderate to deeper bottom areas are covered with a soft to flocculant brownish ooze. Since 1945 seagrass bed loss has spread several miles south from Rickenbacker Causeway. Loss of this original bay bottom environment is related to three influences--boat scour, turbidity and silt smothering. (1) Aerial photographs as early as 1940 show the seagrass beds of north central Biscayne Bay to be disrupted by long streaks paralleling the Bay axis. These reflect erosion by propellers and bottom contact from large boat traffic along the intracoastal waterway. As seagrass beds recover only very slowly (Patriquin, 1975), grass beds have largely been eliminated from areas of heavy traffic by large boats.

More recently, severe bottom scour is extending the length of the intracoastal waterway from daily barge transport of oil between northern Biscayne Bay and Turkey Point. (2) Increased turbidity during early urbanization of Biscayne Bay (discussed below) reduced light intensity at the bottom causing seagrass bed loss. (3) Siltation from dredge and fill projects may have caused seagrass bed loss in portions of northern Biscayne Bay. As suggested by McNulty (1970) much of the destruction of bottom environments of the northern Bay sector may have resulted from the combined stress of urbanization influence and community damage during hurricanes.

Loss of seagrass stabilization left the muddy to sandy substrate more mobile and prone to winnowing which in turn depleted the abundant infauna. Seagrass beds have survived or recolonized some of the shallower areas of northern Biscayne Bay. Extensive recolonization cannot occur until turbidity levels drop significantly or until an effective program of transplanting is implemented.

The seagrass-carpeted bottoms of central and southern Biscayne Bay and the Safety Valve flats have remained largely unaffected by urbanization except where small boat traffic has ripped propeller ruts across the flats. The turtlegrass, Thalassia testudinum, takes 6-8 years to heal these narrow wounds, and, though each rut is narrow, repeated rutting has seriously damaged local areas.

The beautiful coral-algal flats such as found on the Safety Valve just south of Soldier Key have largely died off in the vicinity of Key Biscayne, but continue to flourish from Soldier Key south. As recently as 1966, the tidal bars in Bear Cut and at the north end of the Safety Valve had flourishing communities of coralline algae and finger corals (Porites spp). The living communities have been absent since 1971, but coarse skeletal debris of the environment remains.

Marginal mangrove swamps have extended landward in areas dissected by drainage canals and have been eliminated where directly covered by land fill. Elsewhere, these environments remain largely unchanged (see, however, Teas, this volume).

The freshwater marshes and marl flats landward of the mangrove margin have been extensively modified by man's activities. Salt water invasion along drainage canals has eliminated these environments from most of Biscayne Bay. Along the mainland coast of Card Sound and Barnes Sound, the broad freshwater marl flats and swamps have been isolated from freshwater flow from the Everglades by the fill embankment of highway U.S. 1. The calcitic mud environment, dependent on influx of calcium carbonate charged fresh water (Gleason, 1972), is gradually changing to scrub mangrove or freshwater swamp. The freshwater swamps, no longer in the main flow of Everglades discharge, have yielded either to mangrove or upland scrub communities depending on elevation and association with drainage canals.

TURBIDITY

By far the most noticeable, serious, and complex problem associated with urbanization of Biscayne Bay has been the increase in turbidity of the Bay waters. The influence in turbidity, caused by fine particulate matter in suspension, has largely been restricted to northern Biscayne Bay, although in recent years more persistently turbid waters are noticeable well south of Coconut Grove and Key Biscayne. Barge and tugboat traffic to Turkey Point has somewhat increased turbidity levels in southern Biscayne Bay. The increase in turbidity of Biscayne Bay is serious because (a) high persistent turbidity levels reduce light intensity to the bottom inhibiting desirable bottom environments and biotic communities from returning to and flourishing in northern Biscayne Bay, (b) it shows that previously efficient sediment trapping and bottom stabilizing environments are ineffctive, which means that (c) adsorbed pollutants introduced into the Bay may be widely dispersed through the bay system.

Essentially no attempt has been made to understand and solve the turbidity problem in Biscayne Bay. There are a variety of possible parameters that may influence turbidity levels. Some progress into the problem can be gained by approaching four questions. When did turbidity levels increase in northern Biscayne Bay? What were the possible causes for initial turbidity increases? What is the character of the particulates in suspension? What are the present possible influences that are perpetuating high turbidity levels in northern and north central Biscayne Bay?

Causes

Turbidity levels of northern Biscayne Bay appear to have increased during the 1920's and remained high through the mid 1950's. There were two main sources for particulate suspensions during this period--dredge and fill operations and raw sewage discharge. The massive dredge and fill projects within and along the margins of northern Biscayne Bay during the 1920's must have yielded large volumes of mud to the Bay causing a sharp increase in turbidity and severe damage to the bottom communities. Added to this damage was stress caused by hurricane scouring of the Bay in 1926 and adjustments of the benthic communities in response to the creation of Baker's Haulover cut and Government Cut.

Superimposed on this initial pulse of turbidity were large volumes of particulate suspensions from the discharge of raw domestic sewage into the Bay. With a steadily increasing population, this discharge steadily increased during the 1930's, 40's and early 50's. Minkin (1949) observed "A boat trip in the bay and out the main channel gives the visitor a chance to contrast the dark brown-gray polluted water near the city with the beautiful green ocean water. The visitor has to go out a mile to get to this clear water, and during the trip out he can get the cooling breezes and fine spray of diluted sewage in his face" (see also Dade County, 1960; Milliken, 1949). By 1955 as much as 60 million gallons of raw domestic sewage was discharging into northern Biscayne Bay (McNulty, 1970). Much of this was focused at the mouth of the Miami River. This influence abruptly ended in late 1955 as the treatment plant on Virginia Key began operation.

These are the likely causes for early turbidity in northern Biscayne Bay. High turbidity levels continue in many parts of northern Biscayne Bay today probably because of some combination of the following influences: upland drainage, persistent re-release of muds from unbulkheaded fill islands and spoil banks (described earlier), continuing dredge and fill projects, industrial and ship discharge, bottom scour by boats and ships, and the loss of "turbidity inhibitors".

Turbidity Inhibitors

The natural system of sedimentary environments contained a series of features that tended to rapidly remove particulate suspensions from the water column and to inhibit remobilization of the muddy bottom. Seagrass beds drew particulate suspensions out of the water column by blade baffling of wave and current energy and by trapping particles on delicate epiphyte growths on the blades. The dense seagrass rhizome-root systems stabilized the mud substrate from winnowing during storms. An abundant bottom grazing and burrowing fauna packaged much of the bottom mud into sand sized fecal pellets--much more resistant to redispersion into the water column than the fine mud. At the bay margins, mangrove swamps served as a permanent depository for storm muds, and sponges on the arching proproots filtered much of the day to day particulate suspensions from the water column.

These turbidity inhibitors are largely lost from northern Biscayne Bay. Some mangroves can be returned by planting artificial spoil islands. Seagrass beds with their important pellet packaging fauna cannot return to the moderate to deeper zones of northern and central Biscayne Bay until turbidity levels are reduced. And the author would suggest that turbidity levels will remain high until seagrasses (*Thalassia testudinum*) has recolonized most of the Bay bottom. Therein lies the major obstacle to the recovery of urbanized Biscayne Bay. It should also be the lesson to guide the development and utilization of southern Biscayne Bay.

RECOMMENDATIONS FOR FUTURE RESEARCH

The sedimentary changes in Biscayne Bay associated with urbanization are easily recognized. Shoreline erosion, changing bay bottom and marginal swamp environments, increased turbidity levels and physical modifications to the Bay's morphology can all be documented by sequential aerial photography, core borings or comparison with earlier literature description. Future research should focus (a) on quantifying the rate and magnitude of detrimental changes, (b) on understanding the dynamics of the changed system (and its unchanged counterpart where possible) and (c) determining the cause for initiating and maintaining the change. There are two high priority research needs that must be met to have the capability both to minimize damage during future development and to undo damage from earlier urbanization.

1. Most needed is a workable understanding of the dynamics of the fine-grained sediment system. It is the fine particulates that are most responsive to change, most rapidly dispersed, the cause of turbidity and the transport medium for adsorbed pollutants. Research should be in part interdisciplinary with studies on storm circulation, water column chemistry and trace metal and pollutant analyses. The program should seek qualitative and quantitative understanding of:

a) Turbidity - what are the particulate suspensions in different Bay sectors through the year and at different wave energy levels?

b) Fine-grained sediments - what are the fine constituents of the bottom sediment? What have been historical changes in organized sectors?

c) Turbidity inhibitors - What is the specific influence of sea grasses, pelleters, swamp margins, etc., on drawing suspended sediments out of the water column in different Bay sectors? How has the aerial distribution of these influences changed through time (See 2b below)?

d) Turbidity accentuators - What has caused increased turbidity in certain Bay sectors? What is the relative importance and longevity of these influences?

e) Particulate circulation - What are the rates and patterns of fine grained sediment production, influx, erosion, dispersal, accumulation, and efflux within and between different sectors of the Biscayne Bay system?

f) Cumulative sedimentologic record of circulation and transport-The geometry, historical changes and contained attributes of sediment bodies are (a) a cumulative record of the sediment dynamics and (b) an integrated display of these aspects of the hydrodynamic energy spectrum that move and deposit sediment. This should be carefully studied as a critical compliment to physical oceanographic and sediment transport research.

2. Also of high priority should be careful documentation of the present distribution of bio-sedimentary environments and how they have changed with time. This includes:

a) mapping distribution of bio-sedimentary environments within and marginal to Biscayne Bay to actually determine what is there.

b) determining historical changes in the distribution of bio-sedimentary environments (by sequential aerial photography and core borings) to see what change has actually been associated with urbanization. This should focus on the gradient of change from urbanized (north) to unurbanized (south); and

c) documenting the character and trends of certain bio-sedimentary environments prior to human involvement (by historical maps and analysis of core borings) so as to be able to differentiate natural trends from man-induced influences.

Further research is desired on other problems, such as shore dynamics, but more important is to have what is already known used. Biscayne Bay is unique in many aspects when compared to other urbanized lagoons and estuaries elsewhere in the United States. Existing federal and state guidelines and standards were obtained by studying temperate climate lagoons, river-fed estuaries and open ocean beaches. These standards, in many cases, either are not sufficient or are not applicable to Biscayne Bay. Those local, state and federal agencies responsible for guiding future development must seek the wisdom of scientists that understand a sub-tropical system such as Biscayne Bay.

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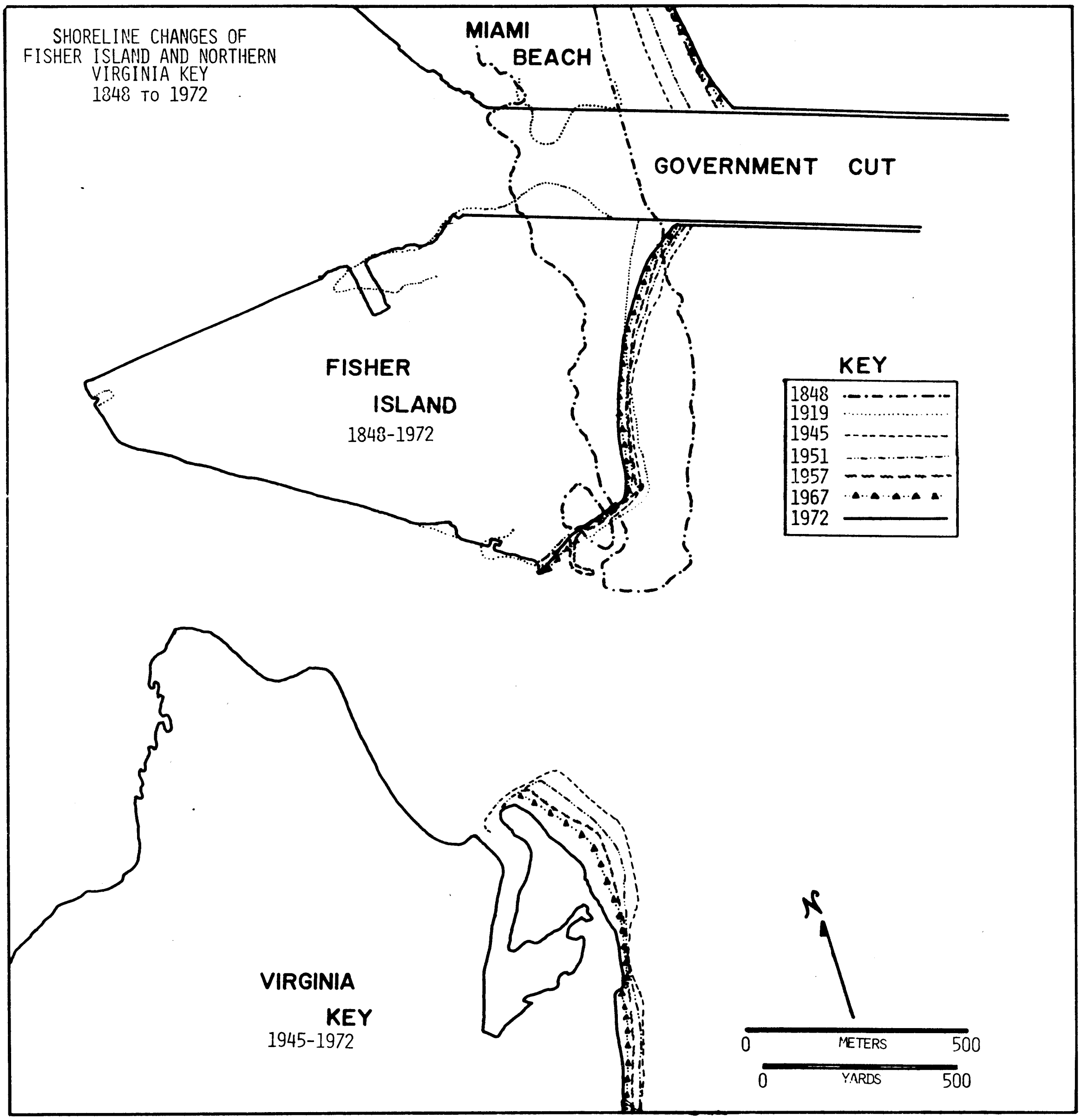

FIGURE 1. Historical shoreline changes of South Miami Beach, Fisher Island, and northern Virginia Key between 1848 and 1972. Partly adapted from Hannon, et al., 1972. Government Cut was dredged in 1905. The seaward extending jetties, completed in 1929, have been a nearly complete block to southerly sand shift causing accretion of South Miami Beach and severe erosion of Fisher Island and Virginia Key Beaches.

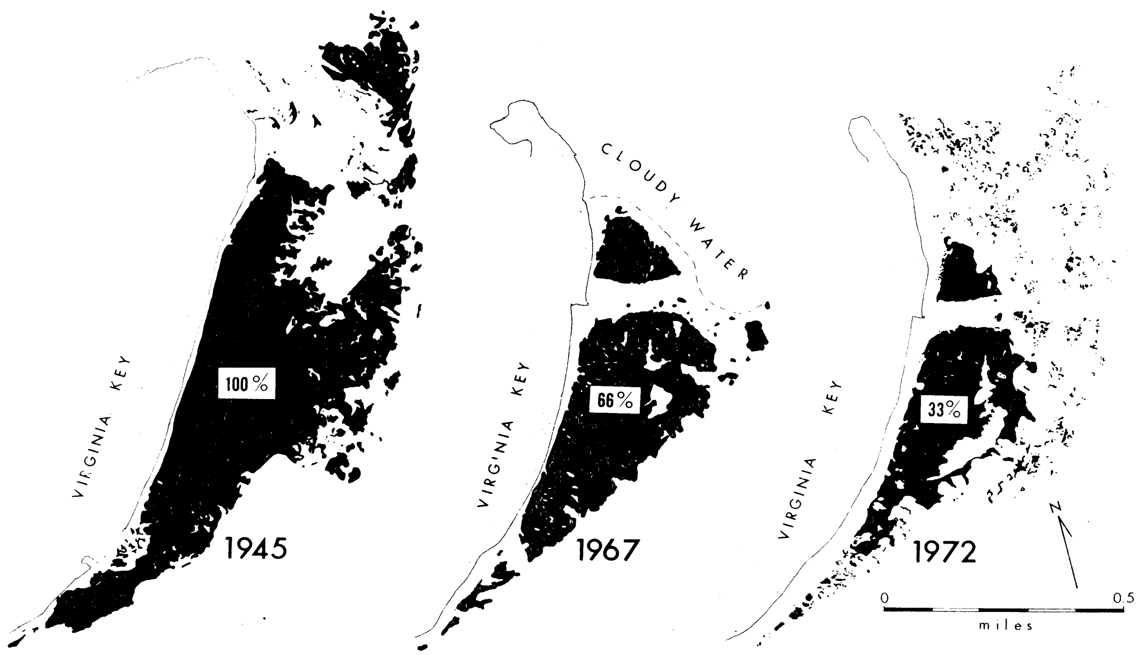

FIGURE 2. Map view of historical changes in sea grass bed cover of the littoral sand platform seaward of Virginia Key beach from sequential aerial photographs. Extensive loss has caused rapid deepening of the platform and erosion of the adjacent beaches.

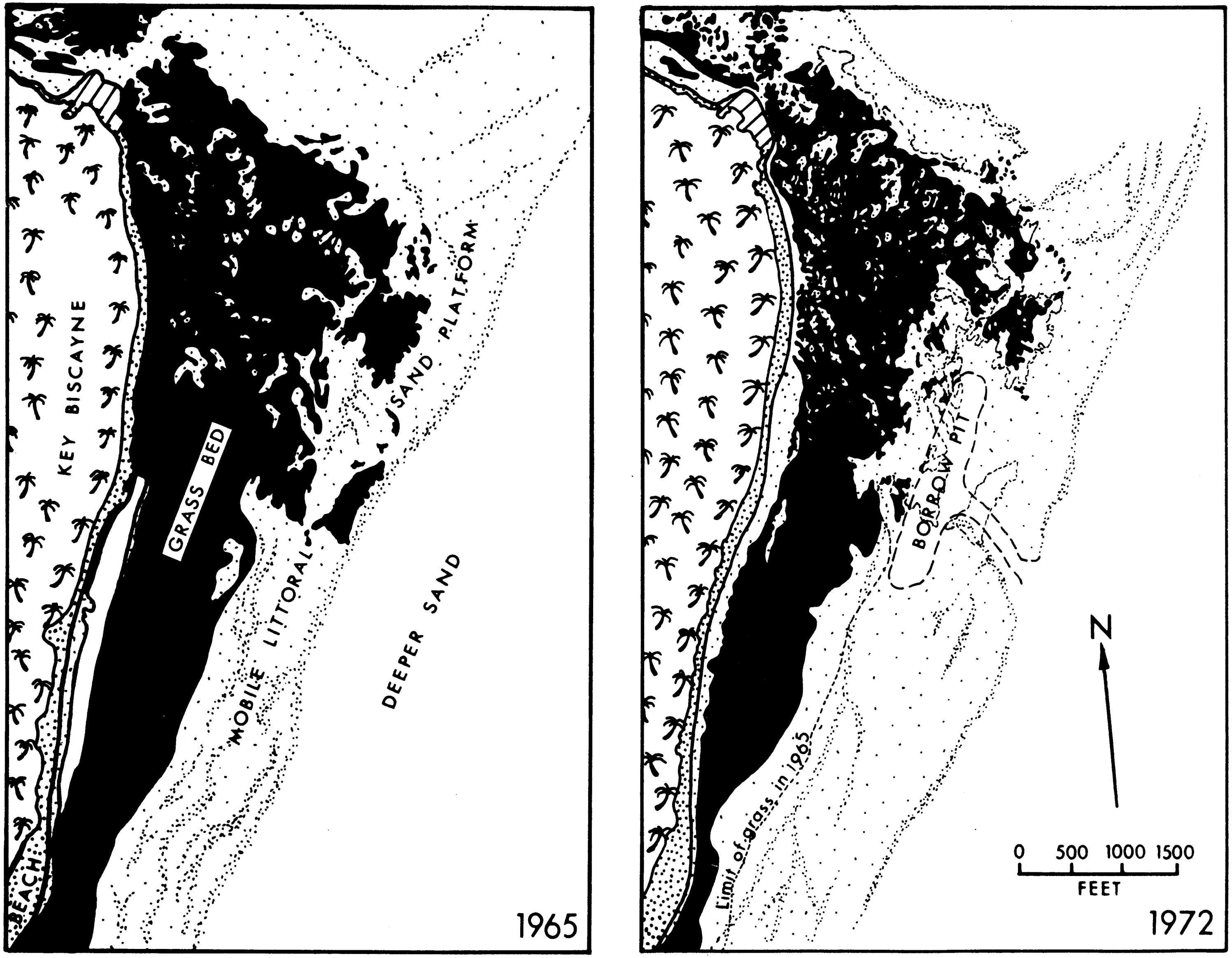

Figure 3. Map view of the nearshore sedimentary environments of northern Key Biscayne in 1965 and 1972. A borrow pit, dredged in 1969, has directly and indirectly caused serious damage to the seagrass cover seaward of this broad shallow littoral sand platform. Data from aerial photographs.